The Diamagnetism of Hydrogen and the Value of the Magneton.

By Major A. E. Oxley, R.F.C., M.A., D.Sc.

(Communicated by Prof. J. W. Nicholson, F.R.S. Received May 29, 1918.)

In previous work on diamagnetism* the author has brought forward evidence that the magneton may prove to be a constituent of diamagnetic as well as of paramagnetic and ferro-magnetic matter.

Certain properties of diamagnetic crystalline media can be interpreted as due to the effects of intense local intermolecular forces which if interpreted magnetically are comparable with the Weiss molecular field in ferro-magnetic substances. This suggests the possibility that in the molecules of diamagnetic substances there may be elements of magnetism arranged in such a way that the molecule is self-compensated, so that experimentally the effect of applying an external magnetic field gives a diamagnetic effect only.

The molecular diamagnetic susceptibility may be represented on the electron theory of magnetism by the equations:—

$$\chi = \frac{N \,.\, n \,.\, \Delta M}{H}; \quad \frac{\Delta M}{M} = -\frac{\epsilon \,.\, \tau \,.\, H}{4\pi m}, \tag{1}$$

where χ = molecular susceptibility.
N = number of molecules per gramme-molecule.
n = number of electron orbits per molecule.
ΔM = diamagnetic moment induced in each electron orbit of moment M by applying an external field H.
τ = period of rotation of electron.
ϵ/m = ratio of charge to mass of electron.

We may write (1) in the form

$$\chi = -\frac{N \,.\, n \,.\, M \,.\, \epsilon \,.\, \tau}{4\pi m}, \tag{2}$$

an equation from which we should be able to deduce M, the magnetic moment of the electron orbit in a diamagnetic molecule, from the molecular diamagnetic susceptibility χ when the values of N, n, ϵ/m and τ are known.

In equations (1) and (2) the effect of the random distribution of the molecular axes has been ignored. The mechanism of the molecule must be such that the change in the period of rotation of the electron (produced by the external field H and giving rise to the induced diamagnetic moment ΔM) is independent of molecular orientation. Indeed Larmor† has shown that the effect of an external field H is simply to superimpose upon the original motions within the molecule an angular velocity $-\epsilon H/2m$ about the direction of H. The magnitude of this rotation is compatible with the values of the induced diamagnetic moment and of the Zeeman separation. Moreover, the sharpness of the lines in the Zeeman separation could not otherwise be readily accounted for.*

---

* 'Phil. Trans.,' A, vol. 214, pp. 109–146 ; vol. 215, pp. 79–103.

† 'Æther and Matter,' p. 341.

It is proposed to apply (2) to the case of hydrogen. Pascal† has shown that the molecular susceptibility of a large number of organic liquids is the sum of the atomic susceptibilities of the component elements, with certain restrictions, depending on the peculiar grouping of the atoms in the molecule. He finds that the atomic susceptibility of hydrogen in combination is $-30{\cdot}5 \times 10^{-7}$, a value nearly equal to that obtained by Kamerlingh Onnes from experiments with liquid hydrogen. It is, therefore, clear, that the hydrogen atom in combination with other atoms in organic liquids differs very little from the hydrogen atom united with another hydrogen atom to form a molecule of hydrogen. We shall take the molecular susceptibility of hydrogen to be $-61{\cdot}0 \times 10^{-7}$.

Now $N = 6{\cdot}8 \times 10^{23}$.

Suppose $n = 2$ (*i.e.* each hydrogen atom has one electron revolving round its nucleus).

$$\frac{\epsilon}{m} = 1{\cdot}73 \times 10^{7}.$$

The period of revolution of the electron τ we shall take to be that corresponding to the H_α line $\lambda = 6563 \times 10^{-8}$ cm.; hence

$$\tau = 2{\cdot}18 \times 10^{-15} \text{ sec.}$$

This, of course, is a definite assumption, but it appears to be a natural one. From (2) we find

$$M = -\frac{\chi \,.\, 4\pi m}{N \,.\, n \,.\, \epsilon \,.\, \tau} = \frac{61{\cdot}0 \times 10^{-7} \times 4\pi}{6{\cdot}8 \times 10^{23} \times 2 \times 1{\cdot}73 \times 10^{7} \times 2{\cdot}18 \times 10^{-15}}$$

$$= 14{\cdot}7 \times 10^{-22}. \qquad (3)$$

Now Weiss has shown from ferro-magnetic and paramagnetic data that the mean experimental value of the magneton gramme is 1123·5, and therefore the moment of the magneton in the molecules of ferro-magnetic and paramagnetic substances is

$$\frac{1123{\cdot}5}{6{\cdot}8 \times 10^{23}} = 16{\cdot}5 \times 10^{-22}.\ddagger$$

---

* Lorentz, 'Theory of Electrons,' p. 124.

† 'Ann. de Chim. et de Phys.,' vol. 8, p. 19 (1910).

‡ A re-calculation of the value of the magneton based on a new determination of the absolute susceptibility of water gives the value $18{\cdot}5 \times 10^{-22}$ e.m.u., which differs from the value calculated from (2) by about 15 per cent.

This value differs by about 11 per cent. from (3) deduced from the diamagnetic property. In view of the totally different nature of the diamagnetic and paramagnetic properties, this result may be regarded as very suggestive. A hydrogen molecule on this view consists of two atoms each with a single electron. These electrons may revolve in opposite directions, giving a diamagnetic molecule. We have, of course, assumed that the area of the electronic orbits is the same in each hydrogen atom.

In Newtonian mechanics the stability of such a system is impossible. It is not proposed here, however, to deal with this question, but merely to bring forward the numerical data given above, which may subsequently be found to accord with the more recent quantum view of atomic stability.

If diamagnetic substances contain magnetons we may be able to account for the fact that the chemical combination of two diamagnetic substances can give rise to a paramagnetic substance containing magnetons. This is the case, for instance, with the union of copper (diamagnetic) and sulphuric acid (diamagnetic), resulting in the formation of cupric sulphate, which is paramagnetic and contains, according to Weiss, 10 magnetons to the molecule.

Possibly the magnetic properties of the Heusler alloys may be accounted for in the same way, as also the loss of magnetism of manganese steels (manganese itself is strongly paramagnetic) due to the formation of intermetallic compounds. The forces which come into play during the chemical combination may be such as to upset the magnetic equilibrium of each component element.

Assuming that the magneton is a constituent of the hydrogen atom, it is of some interest to note that, according to the view developed above, the existence of one magneton in each hydrogen atom implies that the radius of the electron orbit is about 1×10^{-8} cm.

This can readily be shown as follows:—Assume r to be the radius of the orbit, τ the period of revolution of the electron, and M the moment of the magneton. Then

$$M = \tfrac{1}{2} e \omega r^2 = \frac{\pi e r^2}{\tau}.$$

With $e = 1{\cdot}13 \times 10^{-20}$ e.m.u.

$\tau =$ frequency of the line $H_\alpha = 2{\cdot}188 \times 10^{-15}$,

$M = 16{\cdot}5 \times 10^{-22}$ (Weiss),*

we find $$r^2 = \frac{M\tau}{\pi e} = 1{\cdot}014 \times 10^{-16}$$

---

* If $M = 18{\cdot}5 \times 10^{-22}$ (see footnote, p. 59), we find

$r^2 = 1{\cdot}13 \times 10^{-16}$ $r = 1{\cdot}06 \times 10^{-8}$ cm.

on calculation. Thus, $r = 1 \times 10^{-8}$, which is the generally accepted order of magnitude of the radius of a hydrogen atom.

In connection with our use of the period of the line H_α in this paper, it is interesting to note that on Ritz' theory of the origin of spectral series, this line is given by the vibration of an electron under the influence of a suitably placed elementary magnet which, according to Ritz, is not inconsistent with the magneton itself.

An Outline of a Theory of Magnetic Storms.

By S. Chapman, M.A., D.Sc., Fellow and Lecturer of Trinity College, Cambridge, and Chief Assistant at the Royal Observatory, Greenwich.

(Communicated by Sir F. W. Dyson, F.R.S., Astronomer Royal. Received April 11, 1918.)

§ 1. This paper briefly outlines some results of a study of magnetic storms, the object of which was to ascertain their broad general features, leaving aside individual details and cases. The account is limited in several respects, mathematical developments, in particular, being omitted; this is because the paper is intended to be followed by a more complete discussion, when conditions permit. In this future memoir I hope to deal more adequately with many points here lightly passed over, and especially with disturbance phenomena in polar regions, where magnetic conditions are scarcely ever quiet, and where the divergence between the magnetic and geographical axes of the earth introduces most complication.

Part I.—*The Magnetic Data.*

§ 2. Apparently all great world-wide magnetic storms commence simultaneously to within a few seconds,* over the whole earth, although small local magnetic fluctuations may sometimes mask the commencement at particular stations. It is therefore possible, where we are not concerned with very small time intervals, to speak of "storm time," measured from the beginning of a storm, without reference to any individual locality. In contradistinction to storm time, the same for all stations, is local time, which we shall reckon from local midnight.

§ 3. The principal average features of great magnetic storms, with which

---

* *Cf.* 'Proc. Phys. Soc. Lond.,' May, 1918, and the references there cited.